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AN INLINE AIR FILTER FOR COLLECTING COTTON GIN CONDENSER AIR POLLUTANTS

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INTRODUCTION

In recent years the ginning industry has given more and more attention to the problem of air pollution in and around cotton gins. As a rule, pollution has resulted from the accelerated use of mechanical harvesters by farmers and the increased use of pneumatic conveying equipment by gins. Present harvesting practices have greatly increased the volume of waste material modern gins must handle. This waste and the increased use of air by the gins have resulted in the discharge of large volumes of dust- and lint-laden air into the atmosphere.

Dust and fly lint have plagued cotton gins since their beginning, but the problem was mainly the concern of the gins. In many areas at present however, dust and fly lint put in the air by gins have become community problems because residential and business developments have gradually moved into areas formerly occupied only by the gins. Consequently, communities around gins demand better control of pollutants, and gin employees also want better working conditions. For these reasons the cotton ginning laboratories have worked for several years on ways to reduce or to eliminate the pollution of air inside and outside of cotton gin plants.

Present methods used at many gins do not adequately control the dust and fly lint coming from condenser exhausts. If sized properly, kept dry, and maintained adequately, the screen wire cage performs reasonably well[2]. However, under the best conditions in which the cages are housed in screened rooms, fine fly lint and dust still escape and are discharged into the atmosphere. Settling chambers or dust houses are still used in some areas if space is available and the danger of polluting the air is not great. Most dust houses in use today are too small to collect dust or fly lint properly. Dust

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2/ Harrell, E. A., and Moore, V. P. Trash collecting systems at cotton gins U.S. Dept. Agr. ARS 42-62, 22 pp., illus. 1962.

houses are also a fire hazard and cause the ginner to have to pay high premiums for insurance. Typical examples of the present day condenser exhaust problem are shown in figures 1 and 2. The conditions shown are serious fire hazards.

Figure 1. Typical view of inefficient, improperly engineered screen wire cages on cotton gin condenser exhausts.

Figure 2. Interior of a typical condenser exhaust settling chamber or dust house.

The Southwestern Cotton Ginning Research Laboratory (hereafter called the Ginning Laboratory) has developed a lint cleaner and press condenser exhaust filtering device that is very effective in the collection of gin dust and fly lint. This report gives the research test data on experimentally designed collection devices and sets forth design criteria for similar devices used under varying operating conditions.

LABORATORY DEVELOPMENT

To help alleviate the ginners' dust and fly lint problems the Ginning Laboratory has developed a new filtering unit for use on low-pressure, high-volume condenser exhausts. The filter, known as the inline air filter, is automatic and requires very little attention or maintenance. The new filter can be installed directly in existing exhaust lines without the need of additional fans and other accessories and with the need of only very little additional pipe work.

Essentially the inline filter consists of a fine-mesh filtering screen mounted in an enclosed housing, cleaning brushes, pressure-differential switch, and drive motor. The filtering screen is geometrically shaped like a section from the surface of a cylinder. The cleaning brushes are mounted on rotating arms and travel in a circular arc to match the curvature of the screen (Fig. 3). The arms are chain driven at approximately 20 r.p.m. by a 1/3-hp.

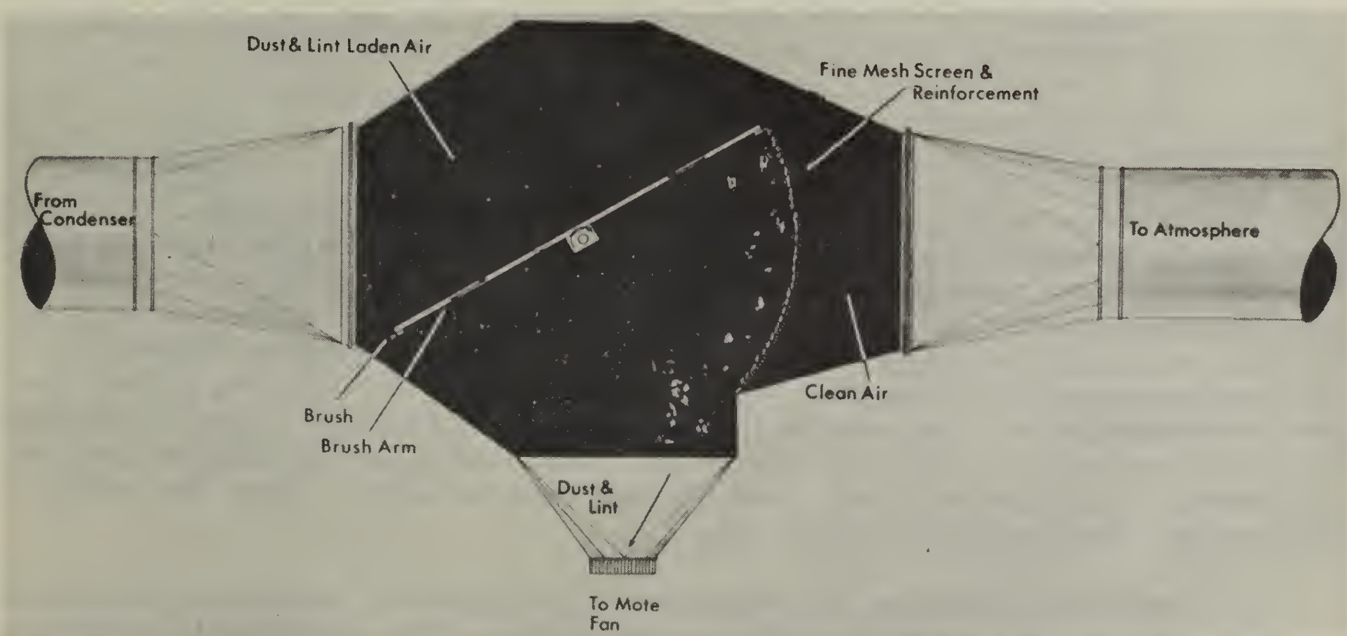

Figure 3. Pictorial cross-section of the experimental inline air filter.

gear-head motor. The action of the whole unit is controlled by a pressure-differential switch (Fig. 4).

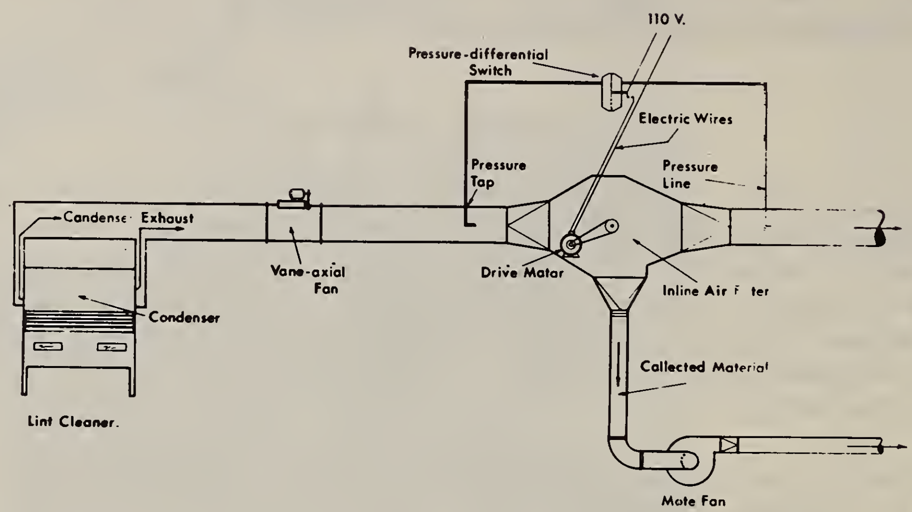

Figure 4. Schematic diagram for inline air filter installation showing motor drive and pressure-differential control switch.

The inline air filter operates on a collecting-cleaning cycle. Fly lint, leaf trash, and dust are caught by the screen during the collecting period. The fly lint that accumulates on the screen also acts as a filter to catch the fine dust particles. As the bat of collected material increases on the screen, back pressure is built up. The back pressure allowable depends on the performance characteristics of the exhaust fan. The cleaning action is started when the back pressure has reached some predetermined level. During the cleaning action, the brushes wipe the collected material from the screen. The brushes stop when the back pressure has been relieved. Then the entire collecting-cleaning cycle begins anew.

The automatic starting and stopping of the cleaning action is achieved by a diaphragm-actuated pressure-differential switch. The differential pressure across the filter screen is imposed on the diaphragm, and the diaphragm assembly moves until it is balanced by an increasing resisting force of a calibrated spring. This movement is transferred to an actuating arm by a microswitch and actuates it to open and close the electrical circuit to the motor, thereby starting and stopping the cleaning action.

The pressure-differential switch can be set to turn on the motor at any desired differential pressure by adjusting the calibrated spring. It is desirable to set the turn-on point of the switch at a differential pressure somewhere near the maximum allowable for the particular system involved. The reason for setting the turn-on point near the maximum allowable back pressure is to take advantage of as much bat formation as possible in order to obtain the maximum filtration of the very fine dust particles. It is very difficult to predict the exact maximum back pressure that a particular system will satisfactorily operate against because the performance characteristics of exhaust fans cause wide variations in condenser exhaust systems.

The lint cleaner and press condenser exhaust fans are generally of two basic types: (a) Propeller-axial flow fans; and (b) vane-axial flow fans. Axial flow fans are designed to handle large volumes of air operating against very low resistance pressure and with a small horsepower demand. As the resistance pressure is increased, the efficiency of axial flow fans and the air volume they can handle are rapidly reduced. Vane-axial fans are designed to operate against somewhat higher resistances than the propeller-axial fans. Cotton gin condenser exhaust systems employing vane-axial fans can usually withstand an additional back pressure of one-half inch to three-fourths of an inch of water. Propeller-axial fan systems operate satisfactorily against an additional back pressure of about one-half inch of water. To insure proper operation of the inline air filter, final adjustment of the differential-pressure switch should be made in the field under actual operating conditions.

The most important component of the inline filter is the filtering screen. In order to catch the fly lint and particles of small trash, it is necessary to use a fine-mesh filtering screen with low back pressure characteristics. Unfortunately, most fine mesh screens have a small percentage of open areas and, consequently, produce rather high pressure drops when air is forced through them. This high pressure drop makes them undesirable for use on low-pressure condenser exhaust systems. However, the Ginning Laboratory uses a type of fine-mesh screen that has a high percentage of open area and it use results in small pressure drops with relatively high air velocities. This type of screen can be used satisfactorily on low-pressure exhaust systems. The screen, known as stainless steel bolting grade wire cloth, is woven from very fine gage stainless steel wire (Table 1). Small wire allows the construction of a fine-mesh screen with a large percentage of open area. A screen with a large percentage of open area and small individual openings allows the filtering of small particles with a minimum of resistance pressure.

Table 1. Specifications for stainless steel bolting grade wire cloth

Mesh 1/ of screen	Wire diameter	Size of opening		Open area	Pressure drop at 1,000 f.p.m. velocity
	Inches	Inches	Microns	Percent	Inches of water
22 by 22	0.0075	0.0380	965	69.7	0.025
40 by 40	.0065	.0185	470	54.8	.066
70 by 70	.0037	.0106	269	54.9	.086
80 by 80	.0037	.0088	224	49.6	.135
105 by 105	.0030	.0065	165	46.9	.165
230 by 230	.0014	.0029	74	46.0	.375

1/ Number of wires per linear inch in perpendicular directions.

FIELD TESTS

The Ginning Laboratory designed, constructed, and field tested two experimental inline filter units at the Mesilla Park Co-op saw and roller gins during the 1963-64 ginning season. A summary of the test results is given in table 2.

One experimental inline filter was placed in an 18-inch-diameter condenser exhaust line coming from a Model 66 Lummus comber lint cleaner.3/ The vane-axial fan was exhausting approximately 5,000 c.f.m. of air to the atmosphere against a static pressure of 4.7 inches of water. The comber lint cleaner received cotton from a Lummus Superjet lint cleaner behind a Lummus 88 gin stand.

The second experimental inline filter was installed in one of the bulk lint cleaner condenser exhaust lines in the roller gin. It was placed in the 18-inch-diameter discharge line from the No. 1 condenser over the first mill-type opener-cleaner section. The vane-axial fan was discharging approximately 3,500 c.f.m. of air to the atmosphere.

3/ Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

Table 2. Summary of inline filter performance, 1963-64 season.

Filter No. and where tested	Bales[1/]	Total material caught	Average weight caught material per bale[1/]	Collection efficiency[2/]			
				Trash	Fly lint	Dust	Overall
	Number	Pounds	Pounds	Percent	Percent	Percent	Percent
1, in saw gin	350	177	0.51	---	---	---	---
2, in roller gin	325	165	51	99+	99+	70	87

1/ Based on the actual number of bales passing through the test condenser.

2/ Efficiency tests were made on the No. 2 inline filter only.

Experimental inline filters No. 1 and 2 were in operation during most of the 1963-64 ginning season. Material collected by each filter was weighed throughout the season, and the number of bales ginned during the collection periods was recorded. From this information an average weight of material collected per bale by each filter was determined. Each filter collected an average of 0.51 pound of waste material for every bale that passed through the condenser to which the filters were attached.

During the ginning season, tests were run on the No. 2 filter to determine its collection efficiency. The air that had already passed through the No. 2 inline filter was then passed through a thick bat of foam rubber, which caught any dust that had escaped the inline filter. Analysis of the material caught by the foam rubber filter along with the weights of the material caught by the inline filter showed that the No. 2 inline air filter was 99 percent + efficient in collecting fly lint and fine leaf trash and 70 percent efficient in the collection of fine dust. The filter had an overall collection efficiency of 87 percent (table 2).

Visual observations during the test runs showed that the small amount of dust not caught by the screen escaped during and immediately following the cleaning action and was less than 165 microns in diameter. As soon as a small amount of lint had accumulated on the screen, very little dust escaped the filter unit thereafter during the collecting part of the cycle.

Field tests showed that the No. 2 inline filter is adaptable to present gin condenser systems. Tests further proved that with minor construction improvements the filter would be a fully automatic, economical, trouble-free method for the collection of dust, fly lint, and fine trash in cotton gin condenser exhausts. In addition, the filter is a major improvement over any other existing method gins now use to collect these fine particles of waste and prevent them polluting the air.

RESISTANCE OF INLINE AIR FILTER

The main total pressure loss in the inline air filter is due to two components--the screen and the housing. The screen produces a pressure loss because it restricts the airflow. The housing produces a dynamic or shock loss because air velocity is rapidly reduced as the air enters the filter unit. These two losses combine to produce the total pressure loss in the unit.

The Ginning Laboratory staff has carefully measured the pressure losses of various mesh screens at different air velocities (Fig. 5). These measurements were made on flat screens mounted perpendicular to the airflow. Measurements were also made on a screen inclined at an angle of 30° to the airflow. No appreciable differences in resistance were noted.

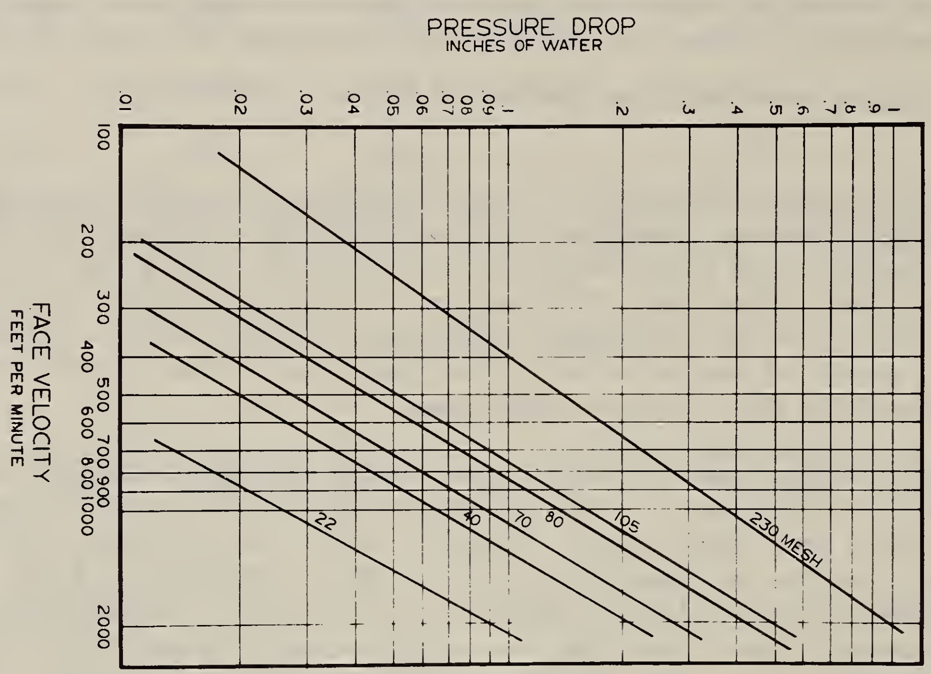

Figure 5. Pressure drop characteristics of stainless steel bolting grade wire cloth.

Shock losses that occur in the housing can be estimated from known engineering data.[4] The shock losses are dependent on the following two factors: (1) The amount of air velocity reduction, and (2) the rate of change at which this reduction occurs. The larger the velocity drop, the greater the shock loss. If this reduction occurs abruptly, the loss will also be greater than if the reduction is accomplished gradually through use of tapered transitions. The proper selection of these transitions is of utmost importance in the design of the inline filter. It is desirable to make the unit as streamlined as practical.

DESIGN CRITERIA

The design of the inline filter may be divided into two phases - screen design and housing design. The procedure for each phase was established by the Ginning Laboratory. The screen design is based on numerous tests conducted at the Ginning Laboratory. The housing design is based on established engineering data.[5]

Screen design procedure is as follows:

1. If possible, determine the type, size, and performance characteristics of the condenser exhaust fan being used.

2. Measure the volume (c.f.m.) of air being discharged by the condenser exhaust fan.[6]

3. Divide the volume of air (c.f.m.) by the design face velocity or air velocity (f.p.m.) through the screen to give the effective screen area required.

4. Divide the effective screen area by the percent of open area of the screen support to give a gross screen area required. The screen supports built by the Ginning Laboratory had an open area of 85 percent (Fig. 6).

4/ American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE guide and data book, fundamentals and equipment pp. 167-168, illus. New York, 1961.
5/ See footnote 4.
6/ Agricultural Research Service. Handbook for cotton ginners, U.S. Dept. Agr. Agr. Handb. 260, p. 65, illus. 1964.

5. The length of the screen arc and the width of the screen can be determined from the relationship that follows. For units designed where the screen arc length is one-fourth of a circle:

Gross screen area = length of the screen arc $\times$ the width of the screen.

$$\text{Gross screen area} = \frac{2\pi R}{4} \times W = 1.57RW$$

where R = radius of the screen arc, π = 3.1416, and W = width of the screen section.

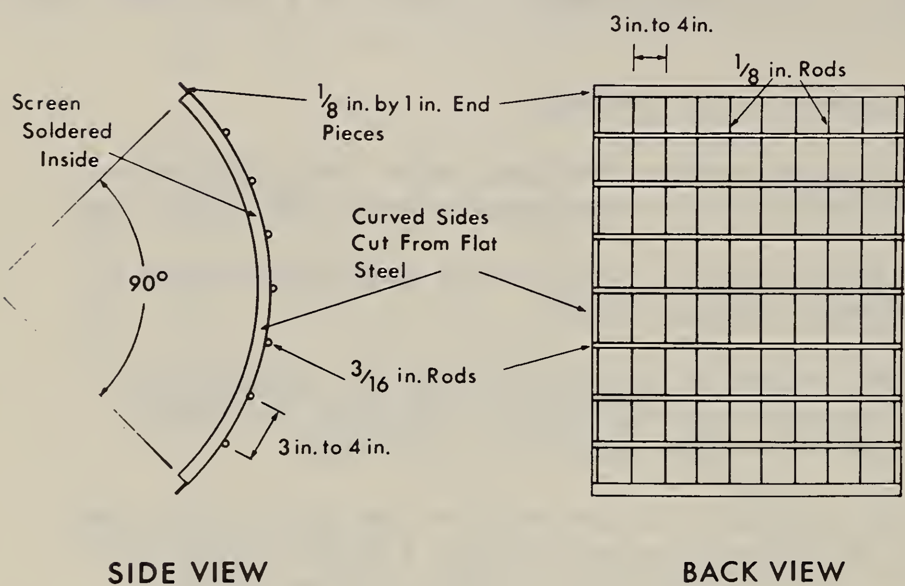

Figure 6. Sketch of the screen support incorporated in the Ginning Laboratory experimental inline air filter

The width W should be equal to or greater than the exhaust pipe diameter d. However, the width W should be less than 1.8 times the radius R in order that the taper of the sides of the inlet transition will be approximately that of the top and bottom taper. Table 3 gives calculated screen sizes for various mesh screens, exhaust air volumes, and exhaust pipe diameters. The data are based on an approximate pressure drop through the screen of 0.1 inch of water. An 85 percent open area was assumed for the screen support. All calculated dimensions are given in the nearest larger even inches for convenience of construction. The exhaust pipe diameters included are standard for most gin manufacturers.

Table 3. Screen sizing table for inline air filter 1/

Condenser discharge measured (cubic feet per minute)	Exhaust pipe diameter (d)	40-mesh cloth 2/ Radius (R)	40-mesh cloth 2/ Width (W)	70-mesh cloth 3/ Radius (R)	70-mesh cloth 3/ Width (W)	105-mesh cloth 4/ Radius (R)	105-mesh cloth 4/ Width (W)
	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Up to 3,000	18	20	18	20	18	20	22
3,000 to 5,000	18	20	22	20	28	20	36
5,000 to 7,000	18 - 26	20	30	24	32	24	42
7,000 to 9,000	18 - 28	24	32	24	42	28	48
9,000 to 11,000	21 - 28	24	40	26	46	32	50
11,000 to 13,000	26 - 28	26	44	28	50	40	48
13,000 to 15,000	28 - 36	28	46	32	52	40	54
15,000 to 20,000	28 - 42	32	54	40	54	40	72
20,000 to 30,000	36 - 42	40	64	44	74	48	90

1/ All dimensions were calculated to nearest even numbered inches. Calculations were made assuming a 15 percent loss in area caused by screen supports.
2/ Sizes based on 1,280 f.p.m. face velocity or approximately 0.1 inch of water pressure drop through screen.
3/ Sizes based on 1,000 f.p.m. face velocity or approximately 0.1 inch of water pressure drop through screen.
4/ Sizes based on 750 f.p.m. face velocity or approximately 0.1 inch of water pressure drop through screen.

Table 4. Inline air filter inlet and outlet transition design dimensions

Exhaust pipe diameter ($\underline{d}$) (inches)	Screen radius ($\underline{R}$)	Transition lengths 1/		
		$\underline{L}_1$	$\underline{L}_2$	$\underline{L}_3$
	Inches	Inches	Inches	Inches
18	20	64	54	22
18	24	86	74	30
21	20	54	44	19
21	24	78	66	27
26	20	40	30	14
26	24	64	52	22
28	24	58	46	20
28	26	68	55	24
28	27	74	60	26
28	32	102	86	36
36	27	52	38	18
36	32	80	64	28
36	40	126	106	44
36	44	148	126	52
36	48	170	146	60
42	32	64	48	22
42	40	108	88	38
42	44	130	108	46
42	48	154	130	54

1/ $\underline{L}_1 = 2.83\ (2\underline{R}-\underline{d})$
$\underline{L}_2 = L_1 - \underline{R}/2$
$\underline{L}_3 = (2\underline{R}-\underline{d})$
See text and figure 7.

The housing design, which is basically the inlet and outlet transition, is such that a practical minimum shock loss (back pressure) will occur. Table 4 gives the calculated transition lengths for the exhaust pipe diameters in relationship to the screen radius R. The taper of the sides is 10° with the center axis. Any increase in this taper will result in an increased pressure drop through the unit owing to an increase in the shock loss. Based on the 10° taper, length $L_1 = 2.83\ (2R-d)$, and length $L_2 = L_1 - R/2$, where R is the radius of the screen arc and d is the diameter of the exhaust pipe (Fig. 7). The taper of the discharge is not as critical in regard to the pressure drop; consequently, length L_3 was arbitrarily set to equal $2R-d$, which will result in a taper of approximately 25°. The outlet transition is only necessary when the unit is installed inside the gin building. When the unit is installed inside the building, the exhaust pipe should be extended to the outside. Also, to avoid a pressure loss due to the abrupt exhaust discharge, a tapered cone having approximately a 10° taper should be attached at the discharge end. For outside installations an outlet rainhood is all that is required beyond the screen (Fig. 7).

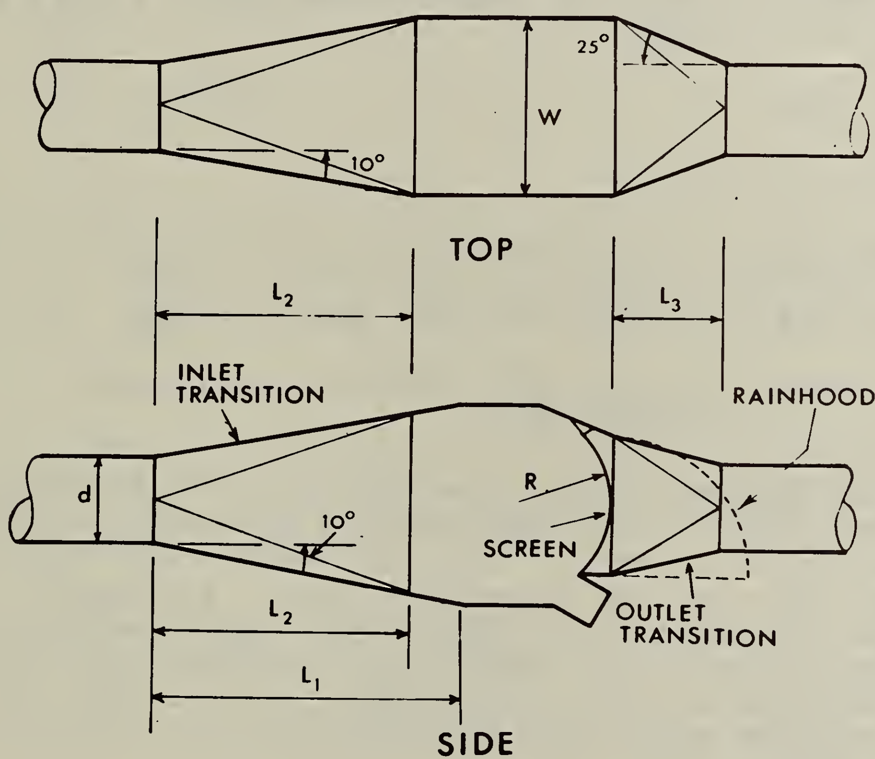

Figure 7. Diagram of inline air filter showing critical design features.

EXAMPLE OF A PROBLEM AND A SOLUTION

Problem

Design an inline air filter for a lint cleaner exhaust that has a pipe diameter of 18 inches and a measured air discharge of 5,000 c.f.m.

Solution

First select a screen mesh for the desired efficiency. A 105-mesh screen is very efficient. The 70-mesh screen will allow more air to pass through the same size unit than a 105-mesh at the same back pressure but at a slightly lower cleaning efficiency (Table 2). A 0.1 inch of water pressure drop occurs in the 105-mesh bolting grade wire cloth with a face velocity of approximately 750 f.p.m. (Fig. 5). In this example 105-mesh wire cloth was selected.

The effective screen area required is $\frac{5{,}000 \text{ c.f.m.}}{750 \text{ f.p.m.}} = 6.67$ sq. ft.

The gross screen area required, assuming 85 percent open area in the screen support, is $\frac{6.67 \text{ sq. ft.}}{0.85} = 7.84$ sq. ft.

From formula (1) gross screen area = $1.57\underline{RW}$.

The width ($\underline{W}$) cannot be greater than 1.8 times the radius $\underline{R}$. If width $\underline{W}$ equals 1.8 times $\underline{R}$, then the gross area = $1.57\underline{R} \times 1.8\underline{R}$ or, 7.84 sq. ft. = $2.83\underline{R}^2$.

Solve for $\underline{R}$:

$$\underline{R}^2 = 2.77 \text{ sq. ft.}$$

$$\underline{R} = 1.67 \text{ ft. or } 20 \text{ in.}$$

Substituting in formula (1), gross area = $1.57\underline{RW}$,

$$\text{width } \underline{W} = \frac{7.84 \text{ sq. ft.}}{1.57 \times 1.67 \text{ ft.}} = 3.0 \text{ ft. or } 36 \text{ inches.}$$

Therefore the calculated screen size has a radius of 20 inches and a width of 36 inches. This solution has yielded a minimum screen radius and the maximum screen width allowable. There are however, any number of size combinations that would meet the design requirement. For example, if a radius $\underline{R}$ of 24 inches had been arbitrarily selected, the width $\underline{W}$ would calculate to be 30 inches. However, the first example, with a minimum radius $\underline{R}$, would allow for the minimum inlet transition length. The space available for the installation of the unit would dictate to some extent the selection of screen radius and width combination.

Select radius (R) equal to 20 inches, and calculate the inlet transition length as follows (table 4):

(2) length $L_1 = 2.83\ (2R-d)$

or, $L_1 = 2.83$ (40 in. - 18 in.)

$L_1 = 62.3$ in.

rounding off this length to the nearest larger even number,

$L_1 = 64$ in.

(3) $L_2 = L_1 - R/2$

$L_2 = 64$ in. - 10 in.

$L_2 = 54$ in.

(4) $L_3 = (2R-d)$

$L_3 = 40$ in. - 18 in.

$L_3 = 22$ in.

According to the forgoing computations, the inline filter would have a radius (R) of 20 inches, a width (W) of 36 inches, and transitions as follows: L_1 64 inches, L_2 54 inches, and L_3 22 inches.

CONCLUSION

The Southwestern Cotton Ginning Research Laboratory has developed an inline air filter as another step to improve air pollutant control in and around the cotton gins. The filter is designed primarily for installation in low-pressure, high-volume gin condenser exhausts.

The experimental inline filter, containing 105-mesh stainless steel bolting wire cloth as the filter media and installed in condenser exhaust line, was 99 percent + efficient in collecting fly lint and fine leaf particles and 70 percent efficient in collecting the dust in the condenser exhaust air. The filter had an overall collection efficiency of 87 percent. Field tests show that the filter is efficient, economical, and trouble free and is well suited to commercial ginning operations.

Design criteria are set forth for sizing the filtering unit for various exhaust systems. However, basic manufacturing construction details have been left to the discretion of industry.

Figure 8 shows a theoretical installation of the inline filter that

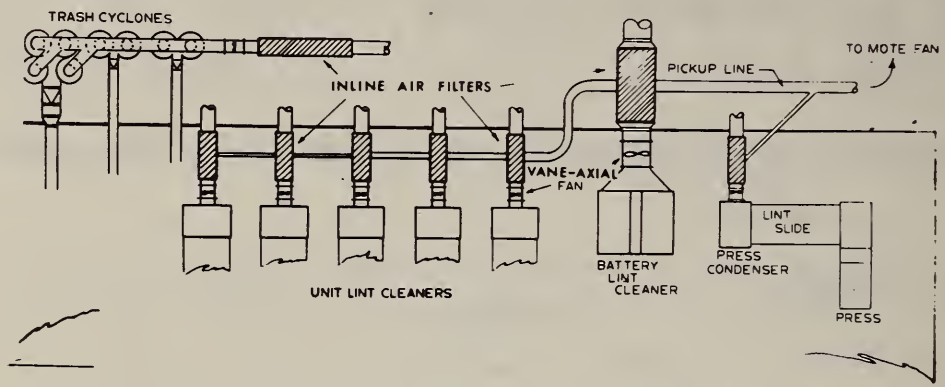

Figure 8. Schematic diagram of a hypothetical installation of inline air filters in a commercial gin's trash disposal system. Note that an inline filter can be used as a secondary collector on cyclone discharge.

will completely control fly lint, fine leaf trash, and dust at a hypothetical commercial gin plant. The inline filter is adaptable for use as a secondary collector for primary cyclone collectors. The exhaust air from the cyclone could be piped through an inline filter designed according to the load from the primary units.